An Integrated Environmental Assessment of the US Mid-Atlantic Region[1]

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ABSTRACT / Many of today's environmental problems are regional in scope and their effects overlap and interact. We developed a simple method to provide an integrated assessment of environmental conditions and estimate cumulative impacts across a large region, by combining data on land-cover, population, roads, streams, air pollution, and topography. The integrated assessment technique identified nine distinct groups of watersheds. Relative cumulative impact scores were highest around major urban centers, but there was not a simple or predictable spatial pattern overall. We also point out the potential applications of this approach that include distinguishing between areas in relatively poor versus good condition, identifying areas that may be more vulnerable to future environmental degradation, and identifying areas for restoration.

Environmental assessments, mandated by the National Environmental Policy Act (NEPA), require examination of cumulative impacts (Shoemaker 1994). Cumulative impact assessment has tended to concentrate on a specific proposed activity (see Fabos 1985) or a potentially threatened resource (Lee and Gosselink 1988). Many of today's environmental problems occur at larger spatial scales that span regions and even continents (Hunsaker and others 1990). including habitat fragmentation and land-use change, modification of streams, and air pollution. As a result, they have the potential to occur at the same place and at the same time. Because of the possibility of cooccurrcnce, their impacts can be cumulative and new approaches are required to provide an integrated assessment.

Like the terms stress, disturbance, and perturbation (see Rykiel 1985), the term impact has been used in many contexts in the ecological literature. It has been used as a synonym for effect when a causal link can be established (Beanlands and others 1986). The term impact comes from the Latin word *impactus, the* past participle of *impingere,* which means to strike against. In an ecological context, the Latin derivative is equivalent to the term disturbance (i.e., a physical force, agent, or process; sensu Rykiel 1985). We use the term here as an equivalent of disturbance, not as a synonym for effect

The recognition of cumulative impacts (Odum 1982) stimulated considerable research in the United States and Canada (*Environmental Management* 1988, Irwin and Rodes 1992, Shoemaker 1994). This research produced a categorization of the types of cumulative impacts (Beanlands and others 1986): (1) multiple disturbances of a single kind overlapping

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Table 1. Indicators of regional ecological conditions

1. Population density (1990)	17. Forest density (1 ha window)
2. Population change (1970-1990)	18. Forest density (65 ha window)
3. Road density	19. Forest density (600 ha window)
4. Percent of watershed in anthropogenic land cover	20. Proportion of watershed that supports forest at three scales (17, 18, 19)
5. Percent of watershed streamlength with roads within 30 m	21. Largest forest patch (expressed as proportion of watershed area)
6. Average atmospheric wet NO_3 deposition (1987 and 1993)	22. Density of forest edges in 1 ha
7. Average atmospheric wet SO, deposition (1987 and 1993)	23. Density of forest edges in 65-ha window
8. Percent of watershed with cropland on slopes >3%	24. Density of forest edges in 600-ha window
9. Percent of watershed with cropland and pasture on slopes >3%	25. Percent of watershed showing vegetation loss
10. Number of impoundments per 1000 km of stream	26. Percent of watershed showing vegetation gain
11. Percent of watershed that is forested	27. Proportion of watershed showing vegetation change
12. Percent of watershed streamlength with agriculture within 30 m	28. Proportion of watershed showing vegetation loss on slopes >3%
13. Estimated N load in streams	29. Vegetation loss in first-order stream region
14. Estimated P load in streams	30. Vegetation gain in first-order stream region
15. Percent of watershed streamlength with forest within 30 m	31. Vegetation change in first-order stream region
16. Soil loss (estimated from USLE)	

‘Population and population change estimates are based on data from US Department of Census. Per watershed estimates of density were based on models m-assigning county estimates to square kilometer cells based on road density (Xie 1995).

[b]Roads and streams are from USGS 1:100,000-scale Digital Line Graph Data (USGS 1989).

[c]Land cover component of indicators 4, 8, 9, and 11 through 24 were derived from ca. 1990 Landsat TM-based land corer data, from Multi-Resolution Landscape Characteristics Consortium (MRLC).

[d]Atmospheric wet deposition data were from USEPA and surface maps of these data were based on modeling at Pennsylvania State University. Values are watershed means in kg/ha/yr * 100.

[e]Slope estimates are from USGS 1:250,000-scale Digital Elevation Model (DEM) Data (USGS 1993).

[f]Soil loss is expressed as the proportion of the watershed where estimated soil loss is greater than 1 ton/acre/yr, based on the USLE model (Wischmeier and Smith 1978).

[g]Nitrogen and phosphorus loads (kg/ha/yr) in streams were estimated using simple screening models (Rechow et al. 1980. Soranno et al. 1996).

[h]Multiple window indicators (17-20 and 22-24) simulate habitat suitability for small, medium, and large wildlife (Riitters et al. 1997).

[i]Indicators 25–31 are bated on multitemporal comparison of Normalized Diierenced Vegetation Indices (NDVI) compiled from ca. 1975 and 1990 Landsat MSS data (North American Landscape Characterization Program), Indicators 25-28 are expressed as a proportion of the watershed area. Indicators 29–31 are expressed as a proportion of the first-order stream region in the watershed. The first-order stream region is that closest to first-order streams.

in time, (2) multiple disturbances of one or more types overlapping in space, (3) indirect effects, and (4) accumulation of small, apparently insignificant disturbances that result in a significant impact in total.

The purpose of this paper is to present a method and results for an integrated assessment of multiple disturbances that overlap in space (item 2 above). The research uses geographic data covering the five mid-Atlantic states of Pennsylvania, Maryland, Delaware, Virginia, and West Virginia. A fundamental difference between traditional and cumulative impact analysis is that the latter takes a broader spatial and temporal view (Preston and Bedford 1988). A broader spatial (and temporal) view requires use of data from satellites and other geographic sources.

Methods

Monitoring and integrated assessment at a regional scale has become feasible because of three recent developments: (1) the availability of remote imagery, (2) geographic information systems (GIS), and (3) advances in landscape ecology. Landscape ecology makes it possible to relate land-cover to a number of ecological variables (Riitters and others 1995, 1996, Jones and others 1997, Wickham and others 1997, O’Neill and others 1997). We analyzed 31 indicators (Table 1) on a watershed-by-watershed basis, using US Geological Survey (USGS) hydrologic unit maps (USGS 1982).

Correlation and minimum-Euclideandistance-to mean cluster analysis were used to identify groups of watersheds with similar data values, and canonical discriminant analysis (CDA) was used to check the distinctness of the clusters. CDA is conceptually similar to principal component analysis in that the input variables can be summarized as a reduced set and the clusters plotted as a function of the canonical scores.

Cluster analysis is an exploratory method that does not have well-developed validation techniques (Aldenderfer and Blashfield 1984). Several iterations of the cluster analysis were performed, using different combinations of variables and transformations. The clustering output that provided the most distinct group ing in canonical space was taken as the solution. Five of the nine clusters from the final output were largely consistent across all iterations.

The final subset of indicators used included items 1, 2, 3, 5, 7, 9, 10, 15, and 20 (Table 1). These variables are related to several different aspects of environmental condition, including population (1, 2, 3), habitat (3, 15, 20), water quality (3, 5, 9, 15), pollution (7, 9, 15), and potential impairment of hydrologic function (10). Pair-wise correlation coefficients were less than ±0.5 except in two cases. Population density (1) and road density (3) had an r value of +0.75. Both were included to weight population more heavily, because many landscape variables (e.g., 9, 15, 20) are predictable when population is high even though the variables are not correlated across all watersheds. Agriculture on steep slopes (9) and proportion of streamlength with adjacent forests (15) were moderately inversely correlated with each other ($r =$ -0.67). Both were included because they measure different aspects of the environment. The former is a measure of potential soil erosion and water pollution (Wiihmeier and Smith 1978, Renard and others 1997), while the latter is a measure of potential habitat and nutrient filtering capacity (Wharton and others 1982, Peterjohn and Correll 1984).

The final subset of indicators was transformed prior to clustering. Square root transformations were used for variables that had observations with zero values, (9, 10, 20). Logit transformations (Evans and Jones 1981) were used for proportions (5, 15), and logarithmic transformations were used for the remaining variables. Data values ranged between -10 and 10 after transformation. Other transformations, including standardizing to a mean of zero and variance of one, did not improve separation in canonical space.

We followed the recommended procedure for identifying clusters, (SAS 1989, p. 883). An initial clustering was run to establish seed values. The initial clusters selected as seed values had at least five observations, and the maximum distance of an observation to the cluster mean was less than the centroid-to centroid distance to the nearest cluster, except in one case. For the one exception, the betweencluster distance (2.37) was slightly less than the within-cluster distance (2.53). A second iteration was run to assign watersheds to clusters based on the seed values established.

The cluster means table provides an integrated environmental assessment and a way to identify relative cumulative impacts. It is an $n \times m$ matrix, where the rows (n) represent the clusters and the columns (m) represent the cluster's mean value for each of the indicators. Thus, the mean values for each of the indicators, taken together, constitute an integrated environmental assessment of watershed groups. Ranking for relative cumulative impact was done by reading down the columns to identify the cluster means representing the poorest conditions. After identifying the poorest values in each column, relative cumulative impact was determined by reading across the rows and tallying the number of poor values. Clusters with a higher total of poor values have a greater relative cumulative impact score than clusters with a lower total of poor values.

Results

Cluster analysis identified nine groups of watersheds (Figure 1). A graph of the clusters as a function of the first and second canonical scores shows that clusters 1, 2, 3, 8, and 9 occupy distinct regions of the X-Yspace, and clusters 5 and 6 are well separated from clusters 4 and 7 (Figure 2). Distinct separation of cluster 5 from 6 and cluster 4 from 7 was evident on graphs of the first and third and first and fourth canonical scores, respectively. The first four canonical variables explained about 96% of the variance in the dam..

Cluster means are shown in Table 2. The rows represent the clusters and columns represent the indicators. The mean indicator scores for each cluster (columns) were separated into three, equal-frequency groups (best, middle, worst). This provided a simple and straightforward way to group watersheds based on indicator scores. The three worst values (highlighted in bold) were tallied across each row to get a relative cumulative impact score for each cluster. Clusters with higher totals of poor values have greater relative cumulative impact scores than clusters with lower totals of poor values. Relative cumulative impact scores ranged from zero to six. Watershed groups are described in rank order in Table 3.

There is no simple spatial pattern to the rankings, such as scores increasing from the less populated west to the more populated east (Figure 1). Only three of the

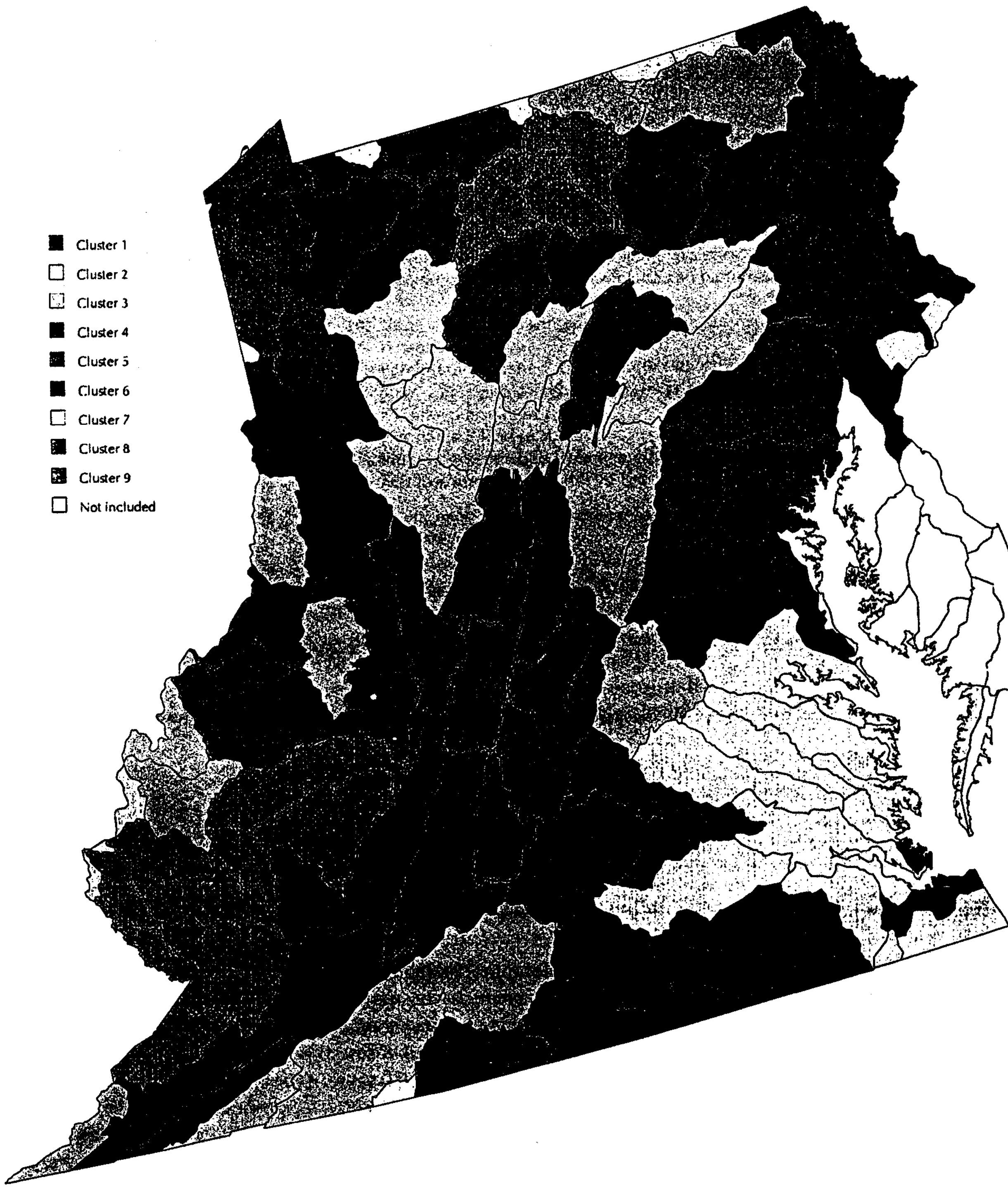

Figure 1. Watershed groups from cluster analysis (see Table 2 for interpretation).

nine groups are spatially contiguous. For example, clusters 3 and 8 are intermingled throughout the Appalachian Mountain region, but have relative cumulative impact scores of 4 and 1, respectively. On average, watersheds in cluster 3 have a greater proportion of their streamlength near roads, a greater proportion of agriculture on steep slopes, less forest adjacent to streams, and less forest in large contiguous blocks.

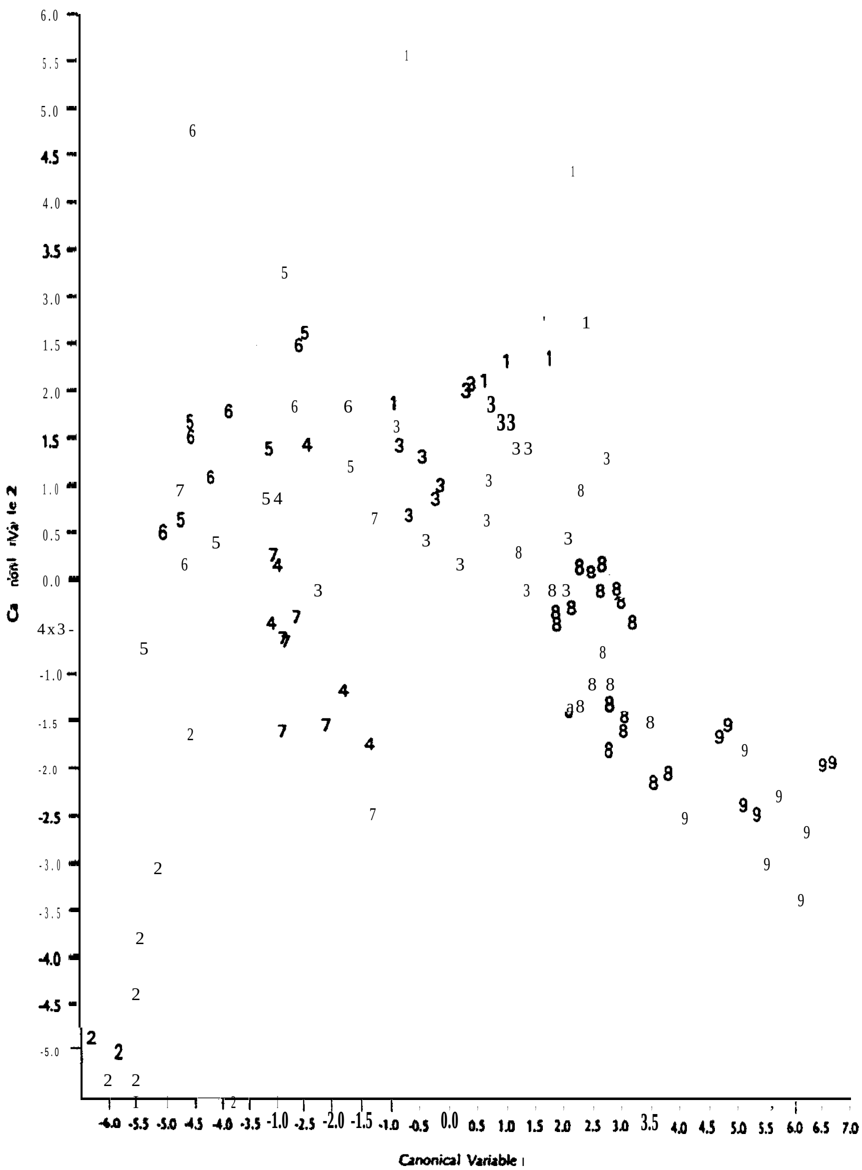

Figure 2. Watershed groups as a function of first and second canonical scores.

Discussion

Many of the indicators used to develop this integrated assessment can be related to aspects of the environment considered important by society (Westman 1977, O'Neill and others 1994, Kepner and others 1995). Indicators C-H in Table 2 provide broad-scale measurements related to the amount and quality of upland habitat and ecological condition of streams. Riparian forests help to prevent pollution (Petejohn and Correll 1984) and provide habitat (Wharton and others 1982). Agriculture on steep slopes increases the potential for soil erosion and delivery of sediment to streams (Wischmeier and Smith 1978, Renard and others 1997). Construction of dams often leads to geomorphic changes, which in turn lead to ecological changes in the stream ecosystem (Ligon and others 1995). Loss of forest removes habitat (Lynch and Whigham 1984), a source of atmospheric carbon sequestration (Wessman 1992), and changes the local climate (Pielke and Avissar 1990).

Mixing indicators of human influence and broad-scale ecological condition to derive relative cumulative impact scores does not necessarily assume that increasing human influence results in degraded ecological condition. There is not a one-to-one correspondence in rank orders of relative cumulative impact scores and population density (see note to Table 2). For example, the population density of cluster 1 is more than twice

Table 2. Cluster means and relative cumulative impact score for watershed groups[a]

Cluster	A	B	C	D	E	F	G	H	R.C.I.
1	21.5	2.5	6.3	8.9	84.5	20.2	2272	42.0	3
2	31.6	1.7	2.5	0.3	82.5	0.6	2435	0.2	2
3	7.5	1.9	6.9	15.2	72.6	16.3	2468	8.7	4
4	-3.5	1.7	1.7	6.0	93.6	5.8	1877	12.0	0
5	10.9	2.4	4.8	20.2	70.8	1.3	2825	2.9	5
6	-2.6	4.1	7.1	7.2	73.6	0.8	2607	15.7	6
7	66.7	1.5	1.9	1.1	88.6	6.7	2056	19.3	2
8	10.1	1.3	5.5	9.7	83.8	37.5	2377	4.4	1
9	-4.0	1.1	9.9	3.3	90.0	69.0	2290	4.3	1

*Population density was not used for relative cumulative impact scoring because county-based population densities were mapped to watersheds using road density. Average population densities for clusten 1-9 are respectively: 175, 111, 88. 28, 325, 982, 78, S8, and 29 persons per square kilometer. A = population change (19704990); B = road density, C = proportion of watershed streamlength that had roads within 30 m; D = proportion of watershed with cropland and pasture on slopes >3%; E = proponion of watershed streamlength with adjacent forest; F = proportion of watershed supporting forest at three scaler; G = average atmospheric sulfate wet deposition (1987 and 1993); H = number of impoundments per 1000 stream kilometers; R.C.I. = relative cumulative impact.

that of cluster 3, but cluster 1 has better scores for most of the broad-scale measurements of ecological condition. Comparison of indicators A, B, and population density with indicators C-H help to show that the relationship between human occupancy of the landscape and ecological condition is not necessarily straightforward.

There are several applications of the cluster means table that are related to environmental analysis and management. First, the cluster means table permits easy identification of the watersheds that are least and most impacted, based on the data used. Second, these data can be used to find watersheds that may be more vulnerable to future environmental degradation. Watersheds in cluster 1 have forests in relatively large,. contiguous blocks, but they also have a fairly high human population density that is increasing rapidly. These watersheds may be more vulnerable to future forest fragmentation than watersheds in other groups. Third, the information in the cluster means table can also be used to guide (and test) ecological restoration (Allen and Hoekstra 1987). For example, watersheds in cluster 4 have a fairly high percentage of forest cover (about 70%), but a low proportion of their watershed area in larger blocks of forest (cluster mean score of 5.8 for variable F in Table 2). Since the abundance of forest interior birds in this region has been shown to be positively correlated with forest size and/or negatively correlated with forest isolation (Lynch and Whigham 1984), reforestation so that large blocks are formed

Table 3. Description of watershed groups based on rankina bv relative cumulative impact score

Rank 1 (Cluster 4): None of the cluster means for this group are among the poorest values. Its cumulative impact score is 0.

Rank 2 (Cluster 9): Watersheds in this group have the highest amounts of forest and riparian cover, and impacts from roads, agriculture, and impoundments are low. This group does have the poorest score for roads adjacent to streams, **and, hence, a cumulative impact score of 1. However, road density is low. The high value for adjacency to streams may be due to the group's occurrence on the Appalachian Plateau where there is a higher proportion of land on steep slopes. There may be a tendency for roads to follow streams along the narrow valleys.**

Rank 2 (Cluster 8): The relative cumulative impact score for thii group is also 1. The group has a poor score for **agriculture on steep slopes.**

Rank 3 (Cluster 7): Watersheds in thii group have a score of 2, with poor scores for impoundment density and rate of population change. Forests also tend to be fragmented into small patches.

Rank 3 (Cluster 2): Watersheds in this group also have a relative cumulative impact score of 2. with significant population increases and forests that arc no longer in large, contiguous blocks.

Rank 4 (Cluster 1): Thii group has a score of 3, with poor *scores* **for population change, road density, and number of impoundments per 1000 stream kilometers. Their score for the amount of forest in large,** *contiguous* **blocks** is in the **upper third.**

Rank 5 (Cluster 3): Watersheds in thii group have a relative cumulative impact score of 4, with poor scores for the amount of roads near streams, agriculture on steep slopes. **riparian** cover, and sulfate deposition.

Rank 6 (Cluster 5): **This** group has a score of 5, with poor scores for road density, agriculture on steep slopes, amount **of riparian vegetation and forest in large, contiguous blocks,** and sulfate deposition.

Rank 7 (Cluster 6): Watersheds in cluster 6 represent the most urbaniied areas in the region, including Pittsburgh, Philadelphia, Washington, and Norfolk. With a relative cumulative impact score of 6. only their values for population change and agriculture on steep slopes are not in the poorest third.

should, over time, result in an increase in the abundance of these species in these watersheds. Watersheds in cluster 4 provide a good opportunity for reconnecting forests so that larger blocks are formed because their overall percent forest cover is already high (Wickham and others 1999).

Summary and Conclusion

Many of today's environmental problems can cooccur in space because they tend to be regional by nature. Their cooccurrence requires that integrated assessments take account of cumulative impacts. We examined the spatial pattern of some regional indicators to develop relative cumulative impact scores for watersheds in the mid-Atlantic region. Relative cumulative impact scores were highest around the major urban centers, but, overall, there was no discernible gradient, such as scores increasing from west to east.

Despite the exploratory nature of cluster analysis, it appears to be a useful tool for grouping watersheds with similar environmental characteristics. Nevertheless, the data and methods used represent only a first attempt at a regional-scale integrated environmental assessment. More. research is needed on other appropriate methods and measurements.

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